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In the matter of United States
 Patent Application
 10/649,720

DECLARATION

I, Michael Bevan Robinson, of Cabinet Hirsch & Associés, 58 avenue Marceau, 75008 Paris, France hereby declare that I am well acquainted with the English and French languages and that the following is to the best of my knowledge and belief a true and accurate translation of the text of French patent Application 02 11128 filed on September 9, 2002, publication No; 2,844,266 entitled ANTI-PMD SYSTEM, which is the priority application for said United States Patent Application 10/649,720.

And I declare this to be true and correct and I understand that willful false statements and the like are punishable by fine or imprisonment or both, under 18 U.S.C. 1001.

Signature

Date

September 25, 2006

Place

Paris, France.

TRANSLATION OF FRENCH PATENT APPLICATION

Publication No. 2,844,260
Application No. 02 11128
Filing Date Sept. 9, 2002
Applicant ALCATEL Société anonyme
Inventors Eric Lainet, Kamel Dougdag and Jean-François Bourhis
Title Anti-PMD system

AN ANTI-PMD SYSTEM

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- The field of the invention is that of anti-PMD systems, the purpose of which is
10 to reduce the polarization mode dispersion (PMD) of an optical fiber during the fiber drawing process. PMD is a problem in an optical fiber because it degrades the signal propagating in the optical fiber. This problem is becoming increasingly severe as the bit rates in optical fiber communication networks increase.
- 15 A prior art anti-PMD system known as the SZ system is based on the use of a flat pulley oscillating in rotation. It is described in US patent 5,298,047, for example, herein incorporated by reference, and in European patent EP 744636. The SZ system includes a flat pulley. A flat pulley is one whose peripheral external surface is cylindrical. The SZ system is positioned at the base of the fiber drawing tower, in the
20 plane through which the optical fiber passes, the optical fiber executing an elbow bend at the flat pulley. The plane through which the optical fiber passes is also known as the fiber drawing plane. The flat pulley, rotating about its rotation axis, also oscillates about the vertical fiber drawing axis, which is coincident with its oscillation axis, and symmetrically with respect to the fiber drawing plane. V-shaped pulleys upstream of the oscillating flat pulley and guide fingers downstream of the oscillating flat pulley guide the optical fiber in the fiber drawing plane. Oscillations of the pulley, alternately from right to left and then from left to right, apply a torsion torque to the optical fiber, which is already covered with its secondary coating. A drawback of this
25 prior art system is that it produces optical fibers whose PMD is still too high.
- 30 The invention proposes an improved anti-PMD system which further reduces the PMD of optical fibers during fiber drawing. To this end, the invention proposes an anti-PMD system based on using a pulley oscillating in rotation and which is convex in order to increase the ratio between, firstly, the angle between the optical fiber in contact with the pulley and the normal to the rotational axis and to the oscillation axis
35 of the pulley and, secondly, the angle between the optical fiber drawing plane and

the normal to the rotation axis and to the oscillation axis of the pulley, to increase the torsion torque applied to the optical fiber to reduce the PMD of the optical fiber. If the ratio between, firstly, the angle between the optical fiber in contact with the pulley and

- 5 the normal to the rotation axis and the oscillation axis of the pulley and, secondly, the ratio between the optical fiber drawing plane and the normal to the rotation axis and the oscillation axis of the pulley increases, for a given amplitude of oscillation of the pulley, the angle between the optical fiber in contact with the pulley and the normal to the rotation axis and the oscillation axis of the pulley increases, which causes the optical fiber to twist more, thereby increasing the torsion torque applied to the optical

10 fiber.

- The invention provides an anti-PMD system comprising a pulley adapted to oscillate in rotation and to apply a torsion torque alternately in the clockwise direction and in the counterclockwise direction to an optical fiber during drawing of the optical 15 fiber to reduce its PMD, in which system a portion of a peripheral external surface of the pulley intended to be in contact with the optical fiber during drawing is convex.

The invention also provides the convex pulley itself, to the degree that said pulley is intended to be used in an anti-PMD system for optical fibers, and where applicable with the optional advantageous features described hereinafter.

- 20 The invention will be better understood and other features and advantages will become apparent in the light of the following description and the appended drawings, which are provided by way of example only.

Figure 1 shows diagrammatically a portion of a fiber drawing system for 25 drawing an optical fiber from a preform.

Figures 2 to 4 are diagrams explaining how the PMD of optical fibers is reduced in a prior art anti-PMD system.

Figures 5 to 7 are diagrams showing how the PMD of optical fibers is reduced in an anti-PMD system according to the invention.

- 30 Figure 1 shows diagrammatically a portion of a fiber drawing system for drawing an optical fiber from a preform, which portion incorporates an anti-PMD system according to the invention. Figure 1 shows the fiber drawing system portion at the bottom of the fiber drawing tower. The optical fiber FO, which has already 35 received its two coatings, moves in the direction of the continuous line arrows. While

still moving vertically, the optical fiber FO is guided by guide pulleys PG. The optical fiber FO then changes direction on passing over the oscillating pulley P'. On leaving the oscillating pulley P', the optical fiber FO is moving horizontally and is guided by guide fingers DG. The capstan, not shown in figure 1 for reasons of simplicity, is situated downstream of the guide fingers DG. Dashed line arrows show the various views used in the subsequent figures.

The various steps of fabricating the optical fiber during the fiber drawing process have a strong influence on the index out of round and the geometry out of round of the core of the preform and consequently also of the optical fiber, which are one cause of high PMD. Optical fibers whose PMD is too high cannot be sold because their PMD would degrade excessively the optical signal transmitted by the optical fiber. The method used to reduce the PMD of an optical fiber during fiber drawing consists in causing the optical fiber to twist, alternately in one rotation direction, for example the clockwise direction, and then in the other rotation direction, for example the counterclockwise direction. The anti-PMD system at the base of the fiber drawing tower, which twists the optical fiber, preferably operates on the optical fiber covered with its two coatings. The torsion torque applied to the optical fiber is transmitted to the viscous glass cone of the preform, situated in the fiber drawing furnace, several meters above the anti-PMD system. The "soft" and twisted glass that is drawn toward the bottom of the fiber drawing tower by the traction of the capstan is then rapidly cooled (this is referred to in the art as "quenching"), which fixes in the glass the torsion exerted by the anti-PMD system. Within reasonable limits, the more the optical fiber is twisted, alternately in one direction and then the other, the lower, and therefore the better, the PMD of the optical fiber. The PMD associated with the index out of round (core index out of round in the plane perpendicular to the light transmission axis) can be corrected by twisting the optical fiber, as can the geometrical out of round. On the other hand, a PMD related to a defect in the glass or to an index variation on the longitudinal axis of the optical fiber would not be modified by the anti-PMD system.

Figures 2 to 4 are diagrams explaining how the PMD of optical fibers is reduced in a prior art anti-PMD system. Figures 5 to 7 are diagrams explaining how the PMD of optical fibers is reduced in an anti-PMD system according to the invention. Figures 2 and 5 are side views of the pulley parallel to the fiber drawing plane and as seen from the capstan. Figures 3 and 6 respectively show the pulley from figures 2 and 5 but when oscillating and as seen from the capstan. Figures 4 and 7

respectively show the pulley from figures 2 and 5 but when oscillating and as seen from underneath the pulley. The direction of movement of the optical fiber is indicated by narrow straight arrows. The direction of oscillation of the pulley is indicated by wide arrows. The direction of rolling of the optical fiber on the pulley is indicated by narrow curved arrows. The pulley oscillating in rotation is denoted P when it is flat, as in figures 2 to 4, and P' when it is convex, as in figures 5 to 7. The peripheral external surface SE of the flat pulley P is cylindrical. The peripheral external surface SE' of the convex pulley P' is toroidal. The optical fiber has portions FOL free of contact with the pulley P or P' and portions FOC in contact with the pulley P or P'.
5 The pulley P or P' rotates about a rotation axis ar. The pulley P or P' oscillates about a vertical oscillation axis av. The normal to the rotation axis ar and the oscillation axis ao is denoted pe. When the pulley P or P' oscillates, the optical fiber upstream of the pulley P or P' arrives at the pulley P or P' at a vertical entry position pve and leaves the pulley P or P' at a vertical exit position pvs. The horizontal offset between the vertical
10 exit position pvs and the vertical axis av is denoted d. The fiber drawing plane is denoted PLF. The angle β is the angle between, firstly, the normal pe to the rotation axis ar and the vertical oscillation axis av and, secondly, the optical fiber portion FOC in contact with the pulley P or P'. The angle α is the angle between, firstly, the normal pe to the rotation axis ar and the vertical oscillation axis av and, secondly, the fiber drawing plane PLF. The angle α is representative of the amplitude of the oscillations
15 of the oscillating pulley P or P'. The offset d and the angle β are representative of the offset of the optical fiber from its equilibrium position, and thus of the effect of the oscillations of the pulley P or P' on the optical fiber, and therefore of the effectiveness of the anti-PMD treatment applied to the optical fiber by the oscillating pulley P or P'.
20 The angle β of the convex pulley P' of figure 7 is substantially greater than the angle β of the first pulley P of figure 4.

The pulley P or P' oscillates about the vertical oscillation axis av. At the entry to the oscillating pulley P or P', the area of contact between the optical fiber and the pulley P or P' has only a very slight influence on the torsion torque exerted on the optical fiber. The action of the oscillating pulley P or P' on the optical fiber is essentially localized between the middle of the contact area FOC between the optical fiber and the oscillating pulley P or P', on the one hand, and the exit from the oscillating pulley P or P', on the other hand. During fiber drawing, the oscillating pulley P or P' turns about its rotation axis ar because it is driven by the optical fiber,
30 which is moving. When the pulley P or P' oscillates, as in figures 3 and 6, the pulley P
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or P' exerts a torsion torque on the optical fiber. This torsion torque accounts for most of the twisting of the optical fiber. The greater the amplitude of the oscillation of the pulley P or P' , the greater the torque exerted by the pulley P or P' , and the more the optical fiber is twisted. Considering the ideal case in which the optical fiber rolls

- 5 without slipping on the pulley P or P' , for a given angular amplitude α of the oscillation of the pulley P or P' , in the case of the flat pulley P , the offset d and the angle β remain relatively low, whereas they become substantially greater in the case of the convex pulley P' , because the optical fiber, no longer being in contact with a flat surface, but instead with a convex surface, moves away more easily from its
10 equilibrium position. At a high fiber drawing rate, the previous results remain valid but their explanation is more complex because of slipping and vibration of the optical fiber. Slipping remains of very limited extent, even at high fiber drawing speeds. It is mostly the vibration that becomes important.

The anti-PMD system according to the invention is no more complicated than
15 the prior art SZ anti-PMD system, which is well known and proven; modifying just one component, namely the oscillating pulley, implements the method according to the invention and significantly improves results in terms of the optical fiber PMD obtained. It is also possible, for an equivalent optical fiber PMD obtained by maintaining the
20 value of the torsion torque applied to the optical fiber, to reduce significantly the angle of oscillation of the oscillating pulley, in order to improve the quality of the coating of the optical fiber. In contrast to what might have been expected *a priori*, the complex character of the pulley does not significantly increase optical fiber coating defects compared to a flat pulley. The effectiveness of a flat oscillating pulley being an increasing function of its diameter, it is possible to obtain the same result in terms of
25 the optical fiber PMD obtained with a convex pulley of relatively smaller diameter as with a flat pulley of relatively greater diameter.

Ranges of preferred values for the radius of the pulley and for the radius of curvature of its convex surface for obtaining the lowest possible PMD of the optical fiber are now specified. Let R be the radius of the pulley and r the radius of curvature
30 of the convex portion of the peripheral external surface of the pulley.

The ratio r/R is preferably from $1/2$ to 1 . The ratio r/R can be from $1/4$ to $1/2$ when the radius R of the pulley is greater than 50 mm and when the amplitude of the oscillations is advantageously also limited to a few degrees on either side of the vertical position of the pulley. Below a particular radius of curvature r , the risk of the optical fiber jumping off the pulley is no longer negligible and problems can arise, as
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much with respect to defective coating of the optical fiber as with respect to defective alignment of the pulley. If the radius R of the pulley is less than 50 mm, the ratio r/R can also be from 1 to 2. Beyond a particular radius of curvature r , the improvement obtained from a convex pulley compared to a flat pulley becomes of increasingly little

5 benefit.

The radius of curvature r of the convex portion of the peripheral external surface of the pulley is preferably constant over the whole of the convex portion of the peripheral external surface of the pulley, i.e. a section through the pulley in a plane of symmetry passing through the rotation axis of the pulley yields a trace of the peripheral external surface that is preferably circular rather than elliptical or conical or some other shape. The prior art pulley is referred to as flat because a section through the pulley in a plane of symmetry passing through the rotation axis of the pulley gives a rectilinear trace of the peripheral external surface. It is preferable if the whole of the peripheral external surface of the pulley is convex, not only its portion intended to be in contact with the optical fiber.

The radius R of the pulley is preferably less than or equal to 100 mm, because beyond this radius the pulley becomes bulky and the improvement in terms of the optical fiber PMD obtained compared to a flat pulley is of less benefit. The radius R of the pulley is preferably greater than or equal to 25 mm in order to prevent the optical fiber jumping off the pulley and escaping from the peripheral external surface of the pulley.

Moreover, a pulley whose peripheral external surface is too wide is of little benefit in that a great portion of the peripheral external surface of the pulley is then not in contact with the optical fiber and is therefore of no utility. The peripheral external surface of the pulley is preferably as regular and as smooth as possible, since asperities could damage the optical fiber coating.

For the same width of oscillating pulley, the greater the radius R of the oscillating pulley, the greater its travel and the greater the risk of the optical fiber jumping off the pulley. The convex oscillating pulley according to the invention allows the use of a pulley of smaller radius for an equivalent result in terms of the optical fiber PMD obtained, with the result that there is no need for guide rims on the convex pulley according to the invention. The convex pulley according to the invention preferably has no guide rims. The oscillations of the pulley advantageously have an angular amplitude that is sufficiently small for the optical fiber not to jump off the pulley despite the absence of guide rims on the pulley.

In the following numerical example, a prior art flat pulley with a radius of 76.5 mm is compared to a convex pulley according to the invention with the same radius and a constant radius of curvature also equal to 76.5 mm. Identical oscillation conditions, expressed in Hertz for the frequency and in degrees for the amplitude, are applied to the two pulleys. The parameter given in the boxes of the following table is the twisting of the optical fiber in turns per meter, which is directly related to the PMD reduction obtained (the higher the number of turns per meter for the twist, the lower the PMD value obtained or, to be more precise, the greater the proportion of heterogeneous core geometry preforms nevertheless yielding low values of PMD in a given population of preforms).

Table

Oscillation conditions	Flat pulley	Convex pulley
4.5 Hz & $\pm 4^\circ$	0.2	2.6
4.5 Hz & $\pm 6^\circ$	3.0	6.7
4.5 Hz & $\pm 8^\circ$	6.4	11.9

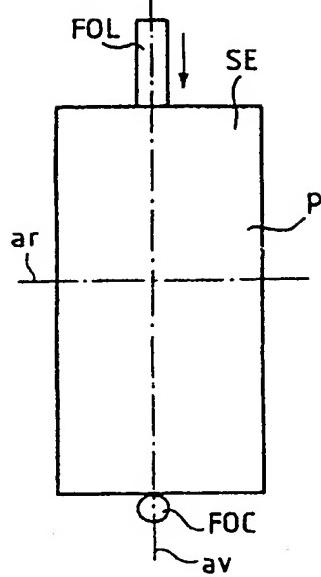
The improvement resulting from the convex peripheral external surface of the pulley is clear from the values in the above table.

CLAIMS

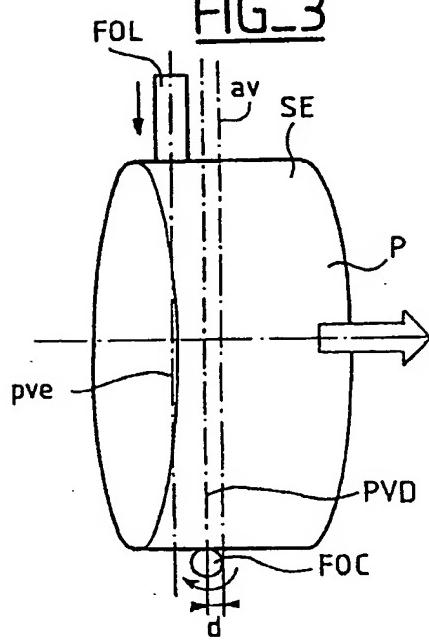
- 5 1. An anti-PMD system comprising a pulley adapted to oscillate in rotation and to apply a torsion torque alternately in the clockwise direction and in the counterclockwise direction to an optical fiber during drawing of said optical fiber to reduce its PMD, characterized in that at least that portion of the outer surface (SE') of the pulley intended to be in contact with the optical fiber during drawing is convex.
- 10 2. The anti-PMD system according to claim 1, characterized in that the ratio r/R is from $\frac{1}{2}$ to 1, where R is the radius of the pulley and r is the radius of curvature of the convex portion of the outer peripheral surface of the pulley.
- 15 3. The anti-PMD system according to claim 1, wherein R is greater than 50 mm and the ratio r/R is from $\frac{1}{4}$ to 1/2, where R is the radius the pulley and r is the radius of curvature of the convex portion of the outer peripheral surface of said pulley.
- 20 4. The anti-PMD system according to claim 1, characterized in that R is less than 50 mm and the ratio r/R is from 1-2, where R is the radius of the pulley and r is the radius of curvature of the convex portion of said outer peripheral surface of the said pulley.
- 25 5. The anti-PMD system according to any one of claims 2-4, characterized in that the radius of the convex portion of said outer peripheral surface (SE') of said pulley is constant over the whole of said convex portion of the outer peripheral surface of the pulley.
- 30 6. The anti-PMD system according to any one of the preceding claims, characterized in that all of said outer peripheral surface (SE') of said pulley is convex.
- 35 7. The anti-PMD system according to any one of the preceding claims, characterized in that the radius of said pulley is less than or equal to 100 mm.
8. The anti-PMD system according to any one of the preceding claims, characterized in that the radius of said pulley is greater than or equal to 25 mm.
- 40 9. The anti-PMD system according to any one of the preceding claims, characterized in that the said pulley has no guide rims.
10. The anti-PMD system according to claim 9, characterized in that the oscillations of said pulley have an angular amplitude that is sufficiently low for said optical fiber not to jump off said pulley despite the absence of guide rims on said pulley.
- 45 11. A pulley intended for use in the anti-PMD system according to any one of the preceding claims.

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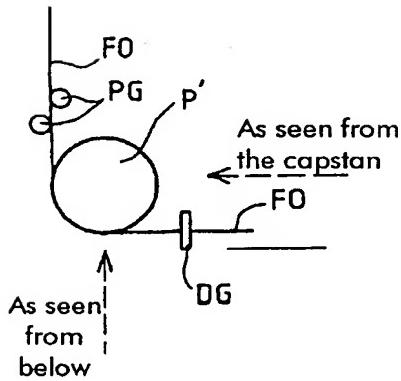
FIG_2



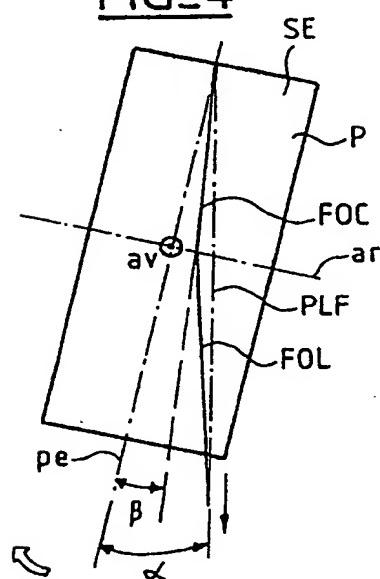
FIG_3



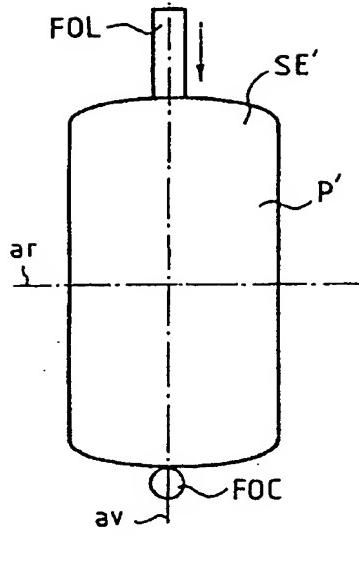
FIG_1



FIG_4

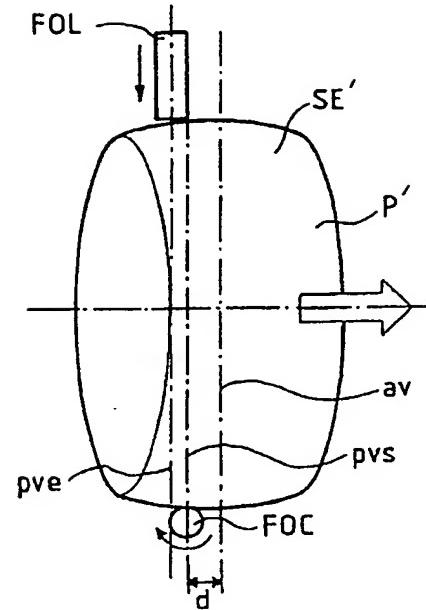


FIG_5



2/2

FIG_6



FIG_7

